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MECHANICAL PROPERTIES OF SILICONE RUBBER IN A CLOSED VOLUME

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report covers an experiment to measure the mechanical properties of four samples of RTV silicone rubber. The test was conducted under conditions of small strains and an elevated hydrostatic pressure component of stress (0 - 4000 psi). The results gave a Young's modulus in the range of 13,000 to 21,000 and a Poisson's ratio range of 0.48 to 0.49. The Young's modulus values were much higher than the usual tensile values; however, a calculation of bulk modulus gave values which were within the accepted range.		

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INTRODUCTION

This report covers an experiment to evaluate the mechanics of RTV silicone rubber products under conditions of small strain coupled with a high hydrostatic component of stress. This condition gives a deviatoric stress component which is small relative to the total stress which may produce certain computational difficulties. A conventional uniaxial compression or tension experiment will yield a value of Poisson's ratio of nearly 0.5 and a Young's modulus of about 1000 psi. In this work a cylindrical compression test specimen was restrained by a steel tube to limit radial deformation. The tube was then instrumented to measure the radial stresses and strains. The average axial stress and strain were derived from the testing machine load and crosshead movement. When this data was reduced, the Poisson's ratio was in the range of 0.48 to 0.49 and Young's modulus was in the range of 13,000 to 21,000. These very high modulus values were not expected and they do not seem to correlate with shore 'A' hardness values.

TEST PROCEDURE

The test fixture is shown in Figure 1. It is a steel cylinder of wall ratio 1.1 with steel end closures. The load was applied in a 120,000 pound universal testing machine set up as a compression test device. The data recorded was:

1. Total load.
2. Crosshead movement.
3. Circumferential strain on the exterior of the cylinder.
4. Axial strain on the exterior of the cylinder.

The first three data items were used to calculate the Young's modulus and Poisson's ratio of the RTV using a strength of materials approach. The last item was used to check assumed condition of zero friction between the steel cylinder and the RTV sample.

DATA REDUCTION

A computer program was written in Fortran 77 to reduce the experimental data. This program performed all required data reduction and checking calculations. A list of these functions is:

1. The zero point correction.
2. Calculate axial strain in the RTV.
3. Calculate radial strain in the RTV.
4. Calculate axial stress in the RTV.
5. Calculate radial stress in the RTV.
6. Calculate Young's modulus of the RTV.
7. Calculate Poisson's ratio of the RTV.
8. Calculate bulk modulus of the RTV.
9. Calculate shear modulus of the RTV.
10. Check the test conditions.
11. Print out the results.

CALIBRATION

Two calibrations were performed. First, a simple experiment was performed to determine Young's modulus for the steel cylinders so that cylinder calculations could be performed using standard Lamé' thick-walled equations for an open-end cylinder. After the four silicone samples were

tested, a hydraulic pressure was applied to each of the two test cylinders; and the recorded strains were entered into the data reduction program as a final check on the assumed properties of the cylinder.

A second check on the test was performed by running a finite element stress analysis on the test fixture using a typical set of data from the experiment. Sample experimental data was extracted from the finite element results and entered into the data reduction program. This was done for assumed silicone-steel friction coefficients of 0.0, 0.1, and 0.2. It was shown that the assumption of zero friction was justified and a coefficient of 0.1 would produce a very large error in the results.

SAMPLE PREPARATION

The test was performed on four samples of RTV silicone rubber supplied by the General Electric Silicone Products Division in Waterford, NY. The material was hand mixed in 600 to 800 gram batches, vacuumed, degassed, and cast directly into one of the two test cylinders. A ratio of ten to one by weight of parts 'A' and 'B' was carefully used. The four samples are defined in Table I.

TABLE I. SILICONE RUBBER MECHANICAL PROPERTIES (CLOSED VOLUME)

Sample Definition of the Material

#	Type	Color	Shore 'A'	Cure	Specific Gravity	Mass gm.
1	RTV-660	White	38	R.T.	1.15	1538
2	RTV-664	Blue- Grey	52	R.T.	1.25	1698
3	RTV-664	Blue	58	160°F 6 hrs.	1.25	1668
4	RTV-680	Beige	69	160°F 6 hrs.	1.49	1936

RESULTS

Figures 2 and 3 show the basic results that were desired. For a further check, the bulk modulus and shear modulus were calculated from the two basic properties. These results are shown in Figures 4 and 5. There were several other more subjective observations which should be noted.

One early observation was that by casting the samples in the test cylinders, an excellent fit was obtained due to the small shrinkage during curing. This was best displayed by the RTV-660 sample which had to be cooled in a storage freezer before it could be removed. The rest could be carefully slid in or out of the cylinder. This demonstrated a small gap between the silicone and the steel cylinder which would have to be closed before any radial contact could be achieved. This effect, added to a poor experimental sensitivity, produced a large scatter in the data at low pressures.

Another observation was the degree of extrusion or cutting of the sample at the joint between the steel tube and the end caps. This effect limited the test load on the RTV-660 sample to a low value and established the maximum load for the other samples. The RTV-680 sample showed no damage due to this problem. However, in no case was any large damage allowed.

After the test was completed, two of the samples were split in half lengthwise to inspect for casting defects. We saw only some minor color variations which were also visible on the exterior of the specimens. This verified the quality of the casting procedure which is regularly used at G.E. Silicone Products.

One detail seems to have produced some interesting results, although it did not seem to be important at the time. The first 664 sample was cast from several one pound kits which were about two years old. The second (number 3) sample was prepared from a fresh 55 pound can. The difference was in the 'B' part of the mix which was the smaller quantity. In the older material the pigment had settled out and was very difficult to remix (in the small 0.09 pound bottle), so a small quantity of fresh material was used to make up the ten to one mix ratio. In this case some of the weight of pigment was replaced by reagent chemicals. This produced more cross-linking of the basic polymer than would occur in an accurately mixed material. The extra cross-linking of the polymer produced an increase in Young's modulus and a decrease in Poisson's ratio. Also noted in the first sample was a change in the pigment content as evidenced by the slight difference in color when the white 'A' part was mixed with the dark blue 'B' part. To help clarify this point, the pigment serves two purposes. First, it aids the evaluation of the mixing

process, and second, it helps preserve a ten to one mixing ratio for many compounds.

DISCUSSION

The first point that should be noted is that there is little correlation between shore 'A' hardness and either Young's modulus or shear modulus which are closely related. However, there is a correlation between shore hardness and bulk modulus. This should be expected because this type of hardness test is essentially a compression test in a closed volume. Add to this the nonlinear relation between bulk modulus (B), Young's modulus (E), and Poisson's ratio (MU).

$$B = \frac{E}{3(1.0 - 2.0 \text{ MU})} \quad (1)$$

In this case a small change in Poisson's ratio can make a large change in bulk modulus as Poisson's ratio approaches 0.5. This is the dominant effect. The RTV-664 sample made from older material had more cross-linking which produced a larger Young's modulus and a smaller Poisson's ratio, which combined to produce a smaller bulk modulus and consequently a small hardness value. This brings up an old question. What do 'hardness' tests actually measure?

Summary of important points:

1. The Young's modulus had a very high value.
2. The two RTV-664 samples yielded rather different results.
3. The bulk modulus results seem to be reasonable.
4. The RTV-660 test was cut off at a lower load because of extrusion around the end caps.

5. Two samples were cut in half to check for interior voids and no visible ones were found.
6. The samples were all removed from the test in one piece. However, the RTV-660 sample had to be chilled to about 0°F.
7. The data under 1000 psi pressure was not reliable because of poor sensitivity of the strain measurement.
8. The difference between the two RTV-664 samples was related to the age of the material which came from two different lots about two years apart in manufacture.
9. The shore 'A' hardness correlates with bulk modulus.
10. Young's modulus and Poisson's ratio are independent properties.
11. There may be a difference in the cross-linking of the two RTV-664 samples.
12. The difference in color between the two RTV-664 samples was created by settling out of the dark blue pigment in the 'B' component of the older material. In this case some newer part 'B' was added to make up the correct weight.
13. The RTV-680 was not in production at the time of the test, so a small custom lot was made for our purposes.
14. It is logical that increased cross-linking would produce a higher Young's modulus and lower Poisson's ratio, but why would this result in a lower bulk modulus and shore hardness?

CONCLUSION

The mechanical properties of rubber like materials derived from conventional tensile or compression tests can yield misleading results when a high pressure component of stress is present. This problem must be solved using special material properties or other constitutive relations.

SILICONE RUBBER TEST CLOSED VOLUME TEST FIXTURE

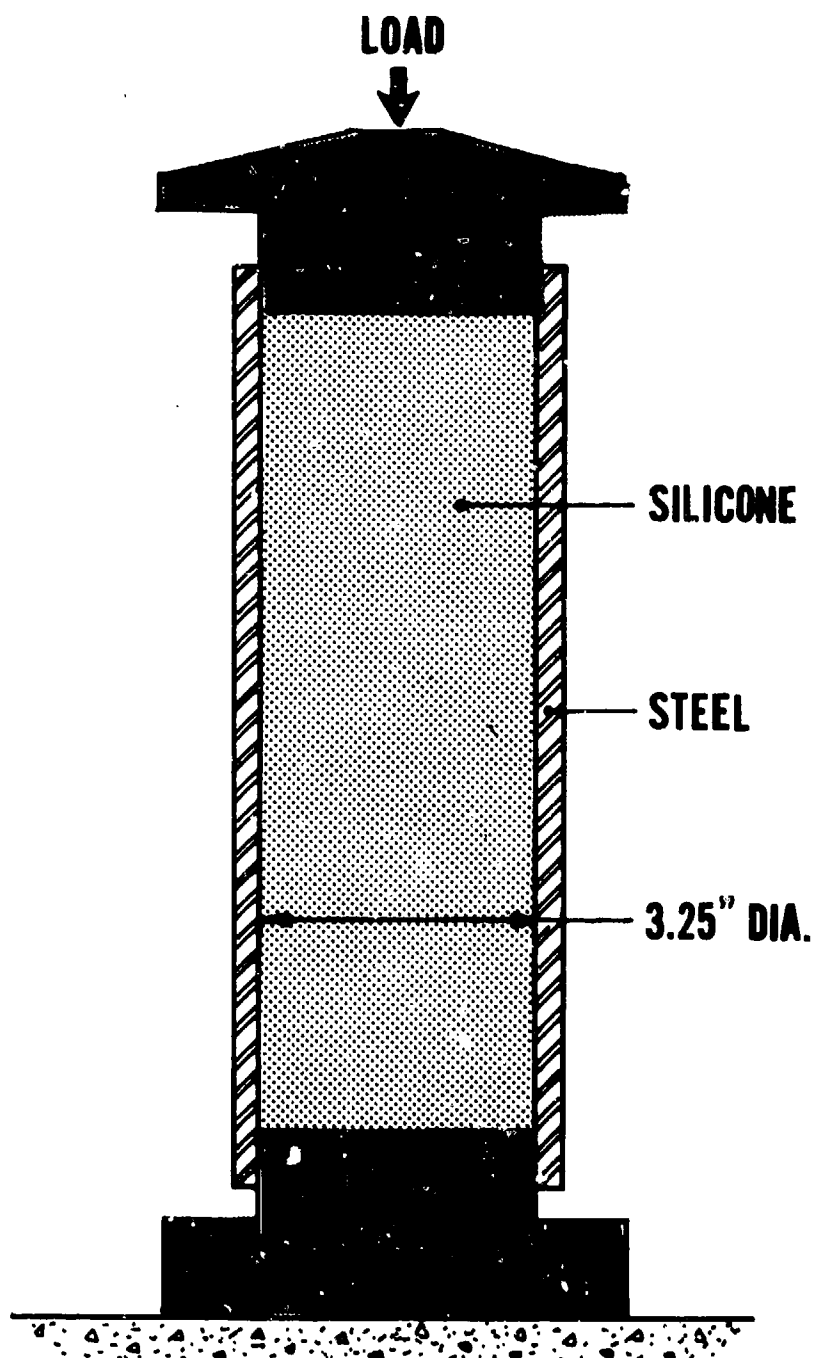
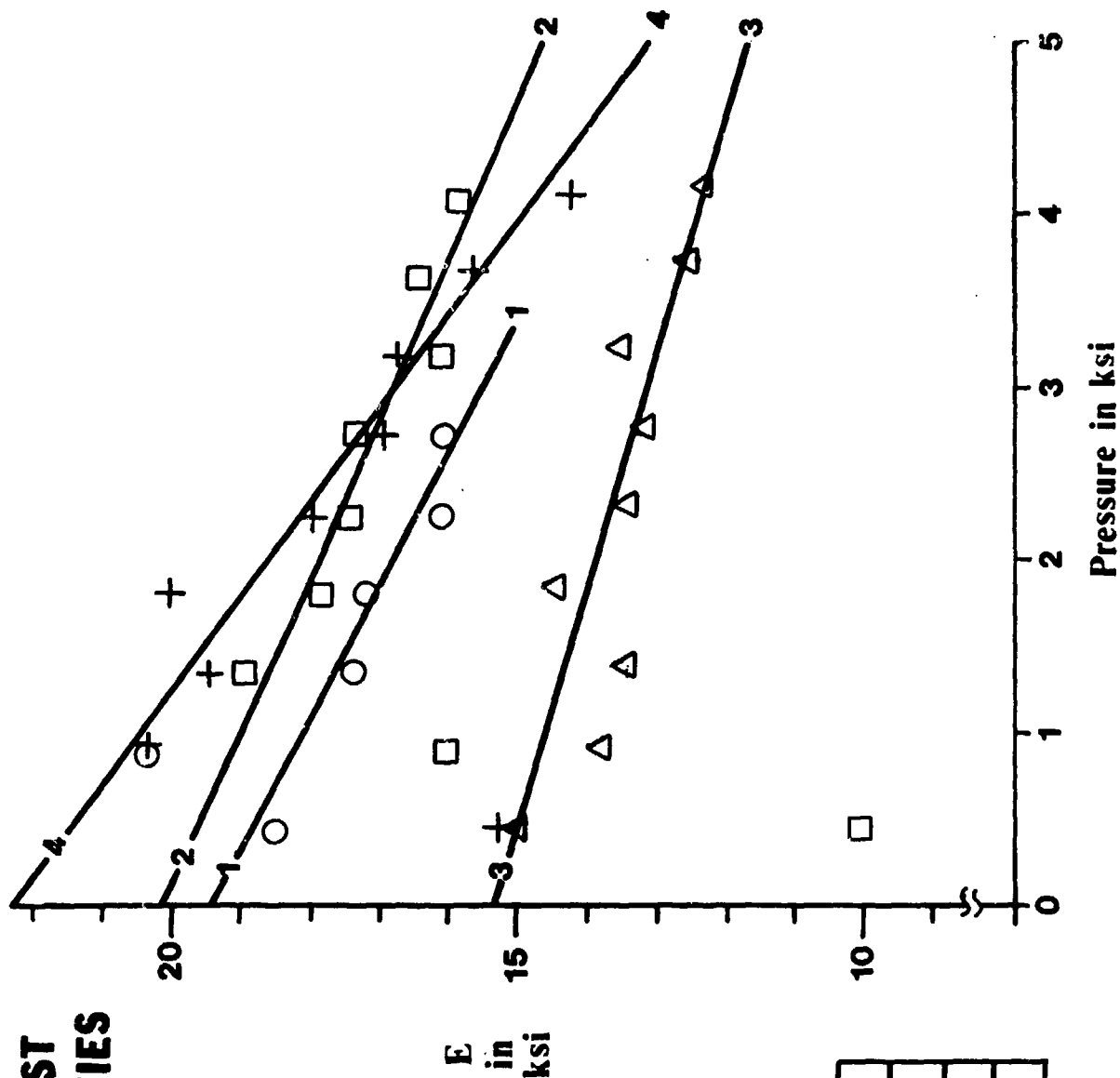


Fig. 1

SILICONE RUBBER TEST MECHANICAL PROPERTIES

**YOUNG'S MODULUS
VS.
PRESSURE**

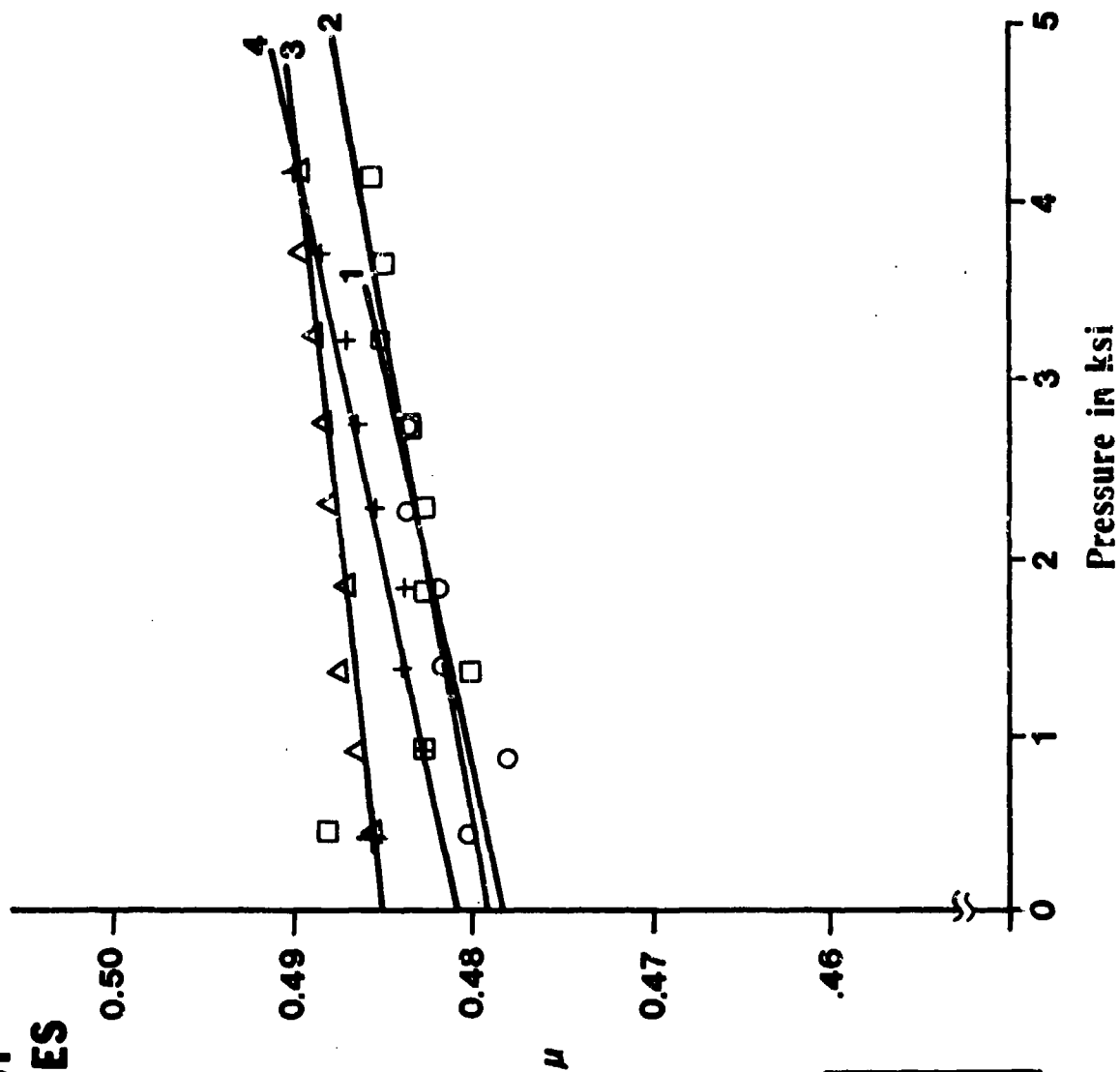


RTV	
1	660 ○
2	664 □
3	664 △
4	680 +

Fig. 2

SILICONE RUBBER TEST MECHANICAL PROPERTIES

**POISSON'S RATIO
vs.
PRESSURE**



RTV	
1	660 ○
2	664 □
3	664 △
4	680 +

Fig. 3

SILICONE RUBBER TEST MECHANICAL PROPERTIES

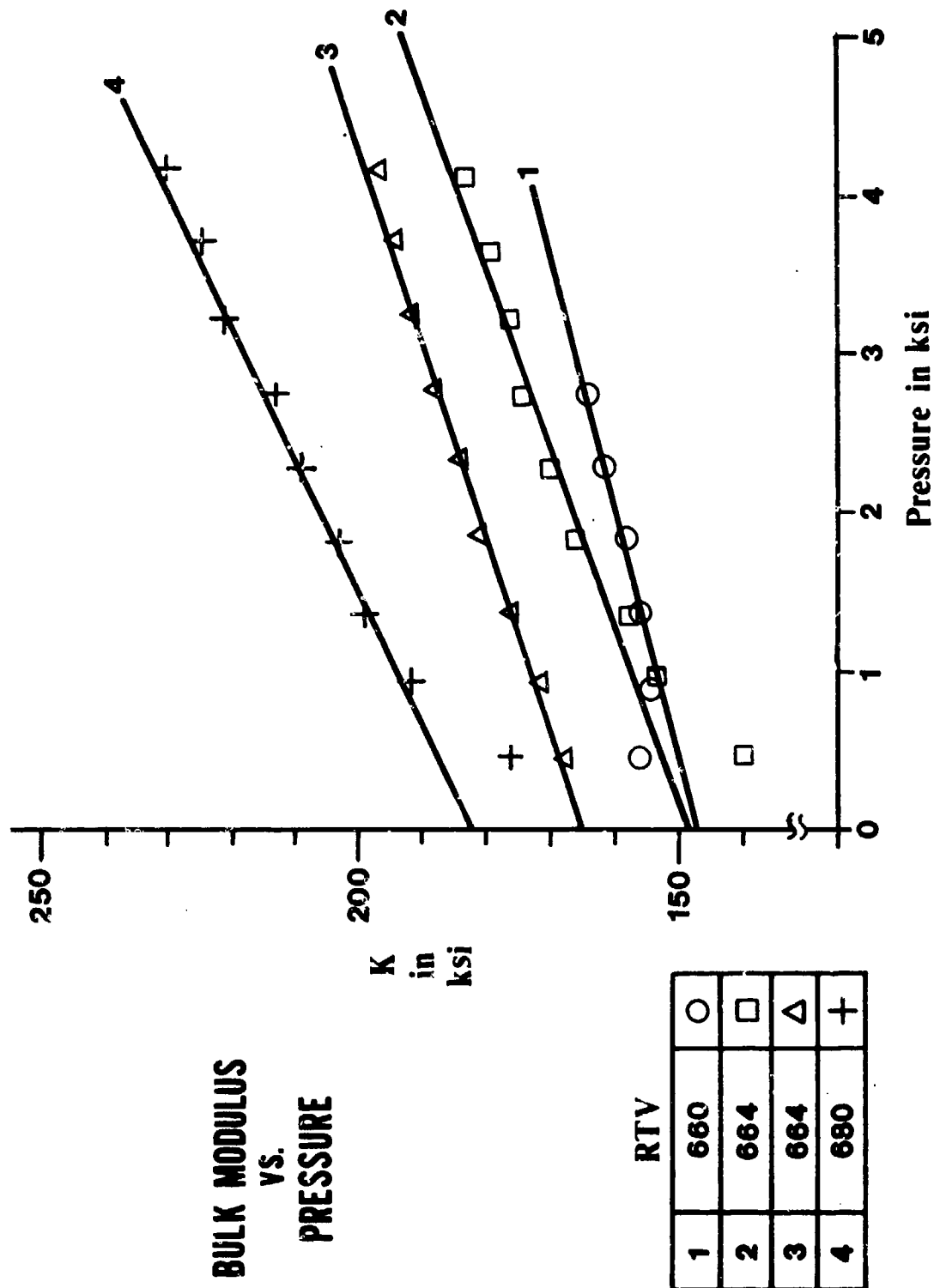
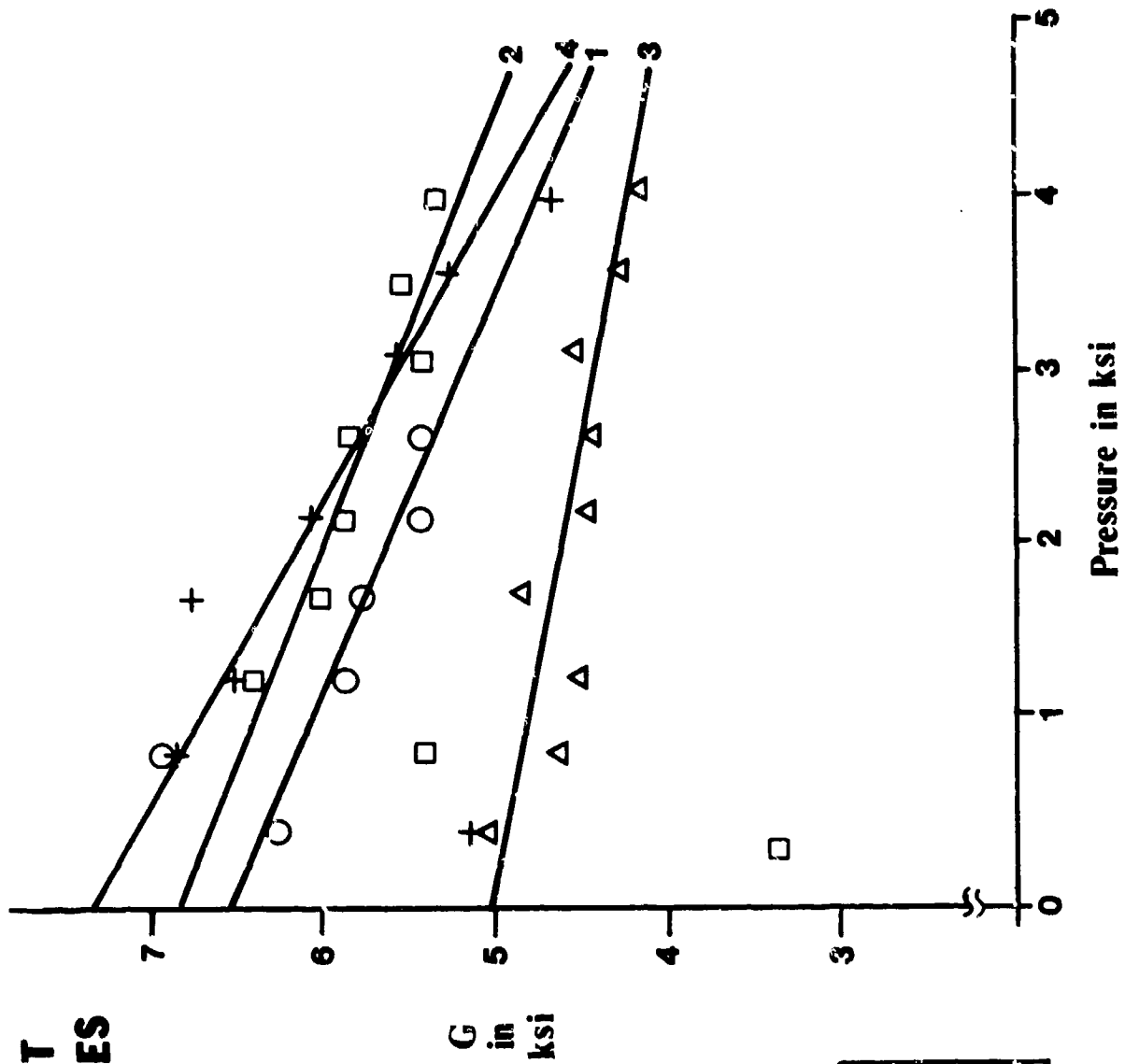


Fig. 4

SILICONE RUBBER TEST MECHANICAL PROPERTIES

**SHEAR MODULUS
VS.
PRESSURE**



RTV	
1	660 ○
2	664 □
3	664 △
4	680 +

Fig. 5

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